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Title: **Prioritising revived species: What are the conservation management implications of de-extinction?**

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Summary:

- De-extinction technology that brings back extinct species, or variants on extinct species, is becoming a reality with significant implications for biodiversity conservation. If extinction could be reversed, there are potential conservation benefits and costs that need to be carefully considered before such action is taken.
- Here, we use a conservation prioritization framework to identify and discuss some factors that would be important if de-extinction of species for release into the wild were a viable option within an overall conservation strategy.
- We particularly focus on how de-extinction could influence the choices that a management agency would make with regards to the risks and costs of actions, and how these choices influence other extant species that are managed in the same system.
- We suggest that a decision science approach will allow for choices that are critical to the implementation of a drastic conservation action, such as de-extinction, to be considered in a deliberate manner while identifying possible perverse consequences.

Key-words: costs, rare-species management, prioritization, decision making

Introduction:

Biodiversity continues to critically decline on a global scale (Barnosky et al. 2011; Ceballos et al. 2015), but recent advances in genetic technology means that the revival of extinct species, or their functional proxies, will be possible in some situations (Church and Regis 2012). As various kinds of de-extinction becomes feasible, it will impact how conservation activities are prioritized and implemented (Pina-Aguilar et al. 2009; Donlan 2014). For instance, one potential conservation benefit of de-extinction is that it allows for an ability to counteract past losses. This provides a second chance for conservation outcomes that until now had been assumed impossible: Species that have already gone extinct could be returned, with ecosystem engineering and trophic impacts for functioning ecosystems (e.g., Zimov et al. 1995; Zimov 2005; Wood et al. 2013). While we acknowledge that none of the current de-extinction pathways would create an exact copy of an extinct species (Shapiro, this special issue), for simplicity here we assume that de-extinction would result in the revival of an extinct species, and in large enough numbers to be re-released into the wild. However, when considering the possibility of de-extinction of individual species, is not sufficient to merely assess the practicality of returning lost species to the wild. We need to also consider the impacts, both direct and indirect, that managing the revived species would have on other species in the system (similar to considerations with rewilding, e.g., Nogués-Bravo et al. In press; Svenning, et. al. 2015). De-extinction could lead to perverse conservation outcomes if it diverted funding from extant species management (Redford, Adams & Mace 2013), if it promoted high risk management activities (Pimm 2013), or if there was an unintended decrease in public support for conservation because there was a perception that extinction was unimportant because it was reversible (Sherkow & Greely 2013). Social perceptions of de-extinction could also impact conservation success if people were concerned about Jurassic Park like mishaps (Crichton, 1990), or if there were economic benefits.

Determining the pros and cons of de-extinction from a biodiversity conservation perspective is difficult because many of the ecological implications are unknown and difficult or impossible to learn. We propose that a careful assessment of the costs, risks and benefits of de-extinction can be obtained using a decision science framework of conservation planning and prioritization (Possingham et al. 2002; Joseph et al. 2009; Gregory et al. 2012; Wilson, Carwardine & Possingham 2009). The exact problem differs depending on whether the decision is for a course of action for one species or for multiple species. In both cases, though, the advent of de-extinction technology can be thought of as the inclusion of a reversible link into the currently one-way path of species moving from being extant to being extinct (Figure 1). Including this link when framing the conservation problem likely changes the choice of which species are allocated resources for recovery. A formal conservation prioritisation approach allows for a determination of which species would be good candidates for de-extinction, which should be prioritized for management to avoid extinction because they would be difficult or expensive to revive, and which could be left to go extinct with the aim of reviving them later when threats are removed.

This paper provides a pragmatic look at how the ability to revive extinct species for release into the wild would impact threatened species management and recovery, and how a decision theoretic approach can be used to carefully think through the consequences of reviving species.   We explore how the prioritization of conservation actions (on the ground by managing agencies) would change if de-extinction were a viable strategy for recovering wild populations. For this purpose, we do not consider legislative, logistical, and moral impediments to de-extinction (e.g., Salsberg 2000).

Conservation prioritization when extinction is reversible:

Conservation prioritization tools and techniques abound, but they are based on similar principles from decision theory. These principles lay out the components of a good decision-making process (Possingham et al. 2002; Gregory et al. 2012) and they will apply to choices about de-extinction as for any other decision. The first step is to 1) clearly define an objective (what are the desired outcomes of the decision) and identify the constraints that limit the ability to meet that objective. The next step is to 2) decide which actions are feasible to perform and then determine the relationship between those actions and potential outcomes. Then, 3) the costs and long term benefits must be determined for each action in relation to desired outcomes, as well as 4) an assessment of the likelihood of success. Finally, a set of actions that meets or approaches the desired objectives can be 5) selected for implementation, based on an optimisation process that incorporates costs, benefits, and likelihood of success. When de-extinction is added as a possible conservation action, the overall objective could still relate to biodiversity conservation (such as to maximise the number of extant native species), and the constraints are still cost and feasibility, but the details of the problem formulation and choices of which components of biodiversity or threatened species are prioritised for funding might change. Next, we discuss how each step in the prioritization process might be modified if de-extinction was an option.

1. Objective

The first step of conservation prioritization is to determine the desired objective(s) of the conservation action (Nicholson and Possingham 2006), and we suggest that relevant objectives could change with the advent of de-extinction. Desired objectives must include consideration of what the endpoint of de-extinction should be. Depending on the conservation objective, de-extinction outcomes range from maintaining viable seed or embryos in the freezer, through regenerating a few individuals to keep in captivity, to establishing self-sustaining populations in the wild in large enough numbers that they are considered secure from future extinction. Here we only consider objectives that aim for self-sustaining populations in the wild, but the capacity for de-extinction may still change how a conservation objective was stated. Many conservation planning initiatives have an objective to “maximize native biodiversity” (Joseph, Maloney & Possingham 2009; Carwardine et al. 2012; Bennett et al. 2014, and many others), but others have different explicit or implicit goals. High profile and ‘flagship’ species, such as those that would have a lot of public interest because they were returned from extinction, can change how the objective is stated. This could lead to single species conservation initiatives focused on species returned from extinction that operate similar to existing tiger or panda conservation programs. The ability to revive these new flagship species might lead to a focus on conservation actions for the revived species ahead of other extant species, or they might focus new attention toward specific regions, habitats, or ecological communities. For example, public support for a conservation project that had an objective to restore sub-arctic steppe grassland ecosystems could be greatly enhanced if mammoths were returned from extinction and introduced to create those grasslands (Zimov et al. 1995; Zimov 2005). This would allow a stated conservation objective of grassland protection to be more popular and potentially more feasible. Finally, public support for species de-extinction could be based on human appeal, scientific interest, and/or economic gain (Salsberg 2000), reinforcing existing biases in conservation programs that are ostensibly designed to conserve biodiversity but tend to favour charismatic species (e.g., Mooers, Prugh & Festa-Bianchet 2007; Schwartz 2008). In such cases the true (and often multiple) objectives of the conservation actions would need to be identified and transparently specified.

2. Actions

De-extinction also has an impact on the choice of actions available for conservation. First, it adds an additional recovery action to the conservation toolbox. Instead of conservation actions being some variety of “protect, manage, move, or do nothing,” there now would be the additional possibilities of “revive now”, “store then revive” or “wait then revive later.” These new actions have two interesting implications that would provide greater flexibility for prioritization across time. First, if de-extinction became commonplace, then critically endangered species need not be treated with a higher sense of management urgency than other less threatened species. Second, the availability of de-extinction actions could change which actions are selected by managers because there is a change in the risks associated with undertaking each action. For example, conservation managers might choose more risky or innovative actions to recover species, knowing that failures in population recovery could be reversible through de-extinction. By providing the potential capacity to reverse mistakes, de-extinction essentially changes the conservation optimization problem from one that deals with a non-renewable resource to one that optimizes a potentially renewable resource (Box 1). Further, it forces us to think more about the timing of actions (Wilson et al. 2011)

3. Costs and Benefits

The benefit of a conservation action is assessed in relation to the stated objective, and is measured as the difference in outcome between if action is or is not undertaken. Including de-extinction actions changes the objective (for example, to a focus on iconic species, or to provide new flagships for ecosystem types; see above), but does not in itself change the way that benefits should be calculated. The outcome or biodiversity gain from undertaking actions may be based on a wide range of factors, such as measures of ecosystem function and resilience, ecosystem services, opportunity and existence values, or maximising species recovery or persistence. The selection of these benefit measures is not determined by the presence or otherwise of a revived species, although de-extinction could add value to intermediary states such as gene banks without a breeding population. More importantly, considering the relevant costs of including de-extinction into conservation prioritisation has a large and direct impact on the expected outcomes. De-extinction could affect conservation management budgets, both by increasing costs due to expensive technologies and management needs, but also by possibly increasing funding for the conservation programs by adding flagship species and attracting previously untapped philanthropic funds. There is a drastic global shortfall in funding for conservation of extant species (James, Green & Paine 1999; Balmford et al. 2003; Waldron et al. 2013; McCarthy et al., 2012), and the costs of de-extinction must be viewed in this context. Here we only briefly examine the cost of the de-extinction process itself and instead focus on the management budget implications of re-establishing a naïve population in the wild.

a. The cost of de-extinction technology

The costs of the initial regeneration are currently uncertain because the technology is largely experimental or hypothetical (Redford, Adams & Mace 2013; Stone 2013), and we do not attempt to estimate these here. Often these costs are considered as resources that sit outside current conservation expenditure. Regardless, we expect that it would likely be analogous to the costs of cloning, which are decreasing significantly over time. These costs also have to reflect the difficulties in obtaining adequate genetic material and establishing reasonably diverse founder populations (Steeves et.al, this issue). Whatever these costs would be, we can assume that they will not be trivial and need to be accounted for in the decision process.

b. Reintroduction costs

Reintroducing captive-raised individuals is an expensive and logistically challenging endeavour (Ewen et al. 2012; Armstrong et al. 2015), even if appropriate habitat was available, and all threats and pressures were adequately mitigated. We assume that any de-extinction initiative would have to rear one or more generations in captivity. There is a vast level of experience in re-introducing a range of extant taxa into many habitat types in many regions. Yet, while key elements of reintroduction processes have been described (IUCN/SSC 2013), and key science questions for future improvements identified, there is still much uncertainty in outcomes of most reintroductions globally (Seddon et al. 2007; Armstrong and Seddon 2008). That uncertainty means that many releases of large numbers of individuals are often required, and intensive outcome monitoring is needed to learn and improve on successes and avoid future failures. It may also require extensive training of animals in behaviour that will allow them to function in the wild – such as foraging, social skills, and predator avoidance (Moseby, Carthey & Schroeder 2015). Depending on the biology of the species, this retraining can be extensive, as demonstrated by the use of microlight aircraft to train captive reared whooping crane (*Grus americana)* chicks to migrate across a continent (Urbanek et al. 2010). It is clear from the level of uncertainty in predicting reintroduction success that the costs of reintroduction are large and unlikely to decline in the near to mid-term (Rahbek 1993). Captive-rearing costs to establish viable populations of extant endangered species (e.g. California Condors (*Gymnogyps californianus*, Walters et al. 2008) and Black-footed ferrets (*Mustela nigripes*, USFWS 2013)) also suggest that the costs of establishing founder populations of iconic extinct animal species will be considerable. For species returned from extinction, there are also unpredictable costs in monitoring and managing adverse effects on extant species as a historic or novel community re-assembles. In addition, because many candidates for de-extinction are likely to have relatively little genetic material to work with, the costs of establishing viable founder populations could be significantly higher than reintroduction efforts for extant species.

c. Management of the species in the wild

We also need to account for the costs of providing and managing suitable areas of habitat for species once they are revived. Habitat acquisition and management of threats in those habitats is often a considerable cost (Wilkie, Carpenter & Zhang 2001; Frazee et al. 2003; Armsworth et al. 2011; Green et al. 2012). Most management agencies are already funding-limited (McCarthy et al. 2012) and many do not have the capacity to adequately manage extant threatened species (Leverington et al. 2010). Adding additional species would likely burden already limited budgets and staff resources. If de-extinct species are prioritised for management, some rare extant species might have to be de-prioritized, with possible negative consequences for those unmanaged species. This suggests a risk of pyrrhic victory, whereby some species are brought back from extinction at great cost, but the diversion of conservation resources allows a greater number to go extinct. This is similar to how increasing funds for flagship species can result in the recovery of fewer threatened species compared to if the same amount was spent on maximising the number of threatened species recovered (Bennett, Maloney & Possingham 2015).

d. Attracting additional funding

The potential impacts of de-extinction on conservation costs are not all negative. It is possible that public interest in resurrected species can be used to increase funding for conservation initiatives. Public interest and support for the long term management of a charismatic species can be an effective means of promoting more general biodiversity goals (e.g., Walpole and Leader-Williams

2002; Smith and Sutton 2008). A recovery program for a high-profile “flagship” species, such as the dodo in Mauritius, could fund management of the species’ habitat and benefit other threatened species that also live there (Verissimo et al. 2011; Bennett, Maloney & Possingham 2015). There is scope for harnessing this public interest to strategically raise money for critical ecosystem restoration and management (e.g. Walpole & Leader-Williams 2002). In such a case, strategic de-extinction of a flagship species could be undertaken as a marketing tool to raise money via tourism or other avenues (Whittle, Stewart & Fisher 2015) to support the recovery of other species in the system (Smith, Veríssimo & MacMillan 2010).

4. Probability of success (feasibility)

A de-extinction effort will achieve the desired outcome with a certain probability of success. Thus, the conservation prioritization problem formulation (Figure 1) needs to also include the probability of successful de-extinction. We use a payoff matrix to illustrate the importance of considering both the probability of persistence and the probability of de-extinction success in the decision process (Figure 2). Here, the manager aims to maximize the total probability of success across two species. If there was sufficient budget to manage both species now, this would clearly be the best option (the top left box). However, if there was only budget to manage one species and the manager was forced to let the other go extinct in the hope that it could be revived later, the choice would depend on the probability of success of both management while extant, and of managing the de-extinction process for each species. In this example, assuming costs and benefits of the actions are similar, the choice would be to manage species 2 and revive species 1 (the circled choice, bottom left).

The probability of successful de-extinction would depend on factors such as availability of genetic resources for regeneration, or efficiency of captive rearing. In addition, for most extinct species, and indeed many of the threatened extant species, relatively little is known about their specific habitat requirements, behaviour, feeding ecology, abiotic and biotic relationships, trophic interactions etc. It is possible to use existing species as surrogates to estimate some of this information. We could base expected mammoth behaviour and habitat use on elephant ecology, or moa interactions on emus (Seddon, Moehrenschlager & Ewen 2014), but there is limited opportunity to learn more about extinct species prior to revival. This is the case even for recent extinctions, where biological specimens exist and limited natural history information was obtained, and is certainly compounded the longer the species has been extinct.

5. De-extinction changes the prioritization ranking

Finally, de-extinction can influence prioritization within a conservation project because it modifies the value we place on securing a viable wild population of a species. Any species that is recovered by de-extinction is likely to be a high priority for maintenance because of past investment in the process of de-extinction, and could be weighted as such in any future prioritization exercises. This is similar to species, such as the North Island Brown Kiwi in NZ (Joseph et al. 2009) or the bald eagle (prior to delisting) on the US Endangered Species List (Schwartz 2008), that are prioritized for spending for reasons other than a basic cost/benefit assessment of actions to provide persistence. One problem with this response could be if de-extinct species remain high priorities for spending expressly because so much money has already been spent on their re-establishment and management, even if it becomes clear that the initiative will be unsuccessful or inordinately expensive (i.e., the "concorde fallacy", http://dictionary.cambridge.org/dictionary/english/concorde-fallacy).

Formulating the problem:

Ultimately, the formulation of the conservation prioritization problem depends on the desired objective and whether one or more than one species is being considered for de-extinction. For the multiple species problem, the objective could be to choose a schedule of actions for each species and time step that maximizes the number of extant native species in the final time-step. The choice of actions per species could be modified by a cost constraint and/or by weighting species by factors such as probability of success, charisma, etc. Important considerations would include which extinct species to include in the prioritization as candidates for de-extinction. Meanwhile, if the problem was being formulated to decide if to revive a single species, the approach would be a similar maximization, but in this the choice would be selecting actions through time to maximize the probability of persistence of that species.

The problem formulation should consider the uncertainty around the data in the prioritization. As for most conservation prioritization exercises, the estimates of costs, benefits, and likelihood of success are likely to include considerable uncertainty. Such uncertainty may be particularly great when the estimate involves long-extinct species, or particularly important when minimizing risk of failure (e.g., losing a species forever) is a goal. Estimates for conservation decision making are often derived from expert elicitation (Martin et.al. 2012), which is subject to considerable uncertainty (McBride, Fidler & Burgman 2012). However, techniques such as eliciting estimates of distributions rather than point estimates (Speirs-Bridge et. al. 2010) can be used to explicitly incorporate uncertainty into prioritization exercises. In addition, adaptive management can be incorporated into a conservation strategy as a method for updating uncertainty over time by learning about the system (Walters 1986).

Summary and Conclusions:

Although de-extinction technology may hold great promise for conservation into the future, possible benefits are likely to come at considerable risk. This paper is a call for using a decision theory approach for conservation prioritization if de-extinction and release into the wild is an option. Choosing which species would be feasible to revive, and understanding the outcomes of those choices, could be achieved by using a decision theoretic framework to identify tradeoffs and uncertainties between different species and actions. Such an approach would allow managers to include revival of extinct species in the same decision-making context as extant species, and thus measure actions against the same objectives. In addition, a combined formal decision-process would potentially highlight extinct species where de-extinction might add considerable value to current conservation initiatives, and identify those species that have a high cost of de-extinction paired with a low probability of persistence. For these latter species the focus should be on the protection of extant populations in the wild because they would not be good candidate species for de-extinction, should they go extinct.

We conclude by reiterating four important considerations that define a conservation prioritization problem that includes de-extinction for release into the wild.

1. Does the habitat of the de-extinct species require specific management that is different to that which is currently occurring? Such management may affect existing species.
2. Did we incorporate the costs of the full de-extinction process – from captivity to training through to maintaining a viable population in the wild?
3. Does the manager's preference towards high risk management actions change when de-extinction is possible? E.g., there may be actions that could have high conservation rewards but be currently not used because of the risk of extinction.
4. Will inclusion of species revival in conservation management objectives result in perverse outcomes, such as increased extinction rates of other species?

We have limited this discussion to the conservation prioritization of de-extinction actions, and there are many other possible issues (technical, ethical, feasibility) that we do not address here. We urge that the de-extinction discussion be placed within a decision science framework, where goals are clearly and explicitly stated and the full range of potential benefits, risks, and costs can be considered by all stakeholders.

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Data Accessibility

This manuscript does not use data

Box 1: De-extinction and management costs in New Zealand

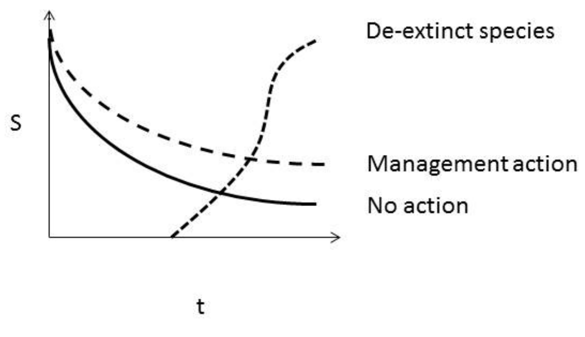
New Zealand has lost 56 species of birds in the past 1000 years. This is a large proportion of the avifauna when compared to the 25 extant species with a current conservation threat status of Nationally Critical (Robertson et al. 2013). Meanwhile, there is a global shortfall of over a billion US dollars for bird conservation needs and the estimated cost of conserving extant New Zealand birds is almost US $ 6000 /HA (McCarthy et al. 2012). If all revived species were to be ranked as critically endangered, then revival of even a small proportion of the extinct species on the list would mean that the total resources available for the conservation management of critically endangered species would need to be spread over 2-3 times the number of species compared to current spending patterns.

Box 2: De-Extinction switches the conservation problem from a non-renewable resource problem to a potentially renewable resource problem

Biodiversity conservation is an optimization problem. In it, we attempt to choose a set of actions (x), that protect as many species (S) as possible (either at the end of the planning cycle (T) or over all time steps), while operating under a cost constraint where all action expenditures (c) are less than the total available budget (B).

$$\max_x S(T) \text{ or } \max_x \sum_{t\in(0\ldots T)} S(t) \quad s.t. \ \sum_{t\in(0\ldots T)} c\ (t,x) \leq B$$

In either case, because resources are limited, the number of species that remain extant declines over time, and the best that spending on an action can do is to slow or stop the decline (solid line and large dashed line in figure below). The advent of de-extinction would fundamentally change the formulation of this problem by removing the irreversibility aspect. This means that spending on de-extinction adds lost species back into the system and may result in more species than at the beginning of the planning cycle (small dashed line in figure).



Because of the change in the impact of actions on the relationship between the number of extant species and time, the available solutions are more flexible. This could enhance conservation outcomes, but could also lead to perverse 'optimal' approaches to maximizing biodiversity.

The addition of a reversible link between extant and extinct species necessitates a reformulation of the conservation prioritization problem. We can think of this as moving from a non-renewable resource (species are gone if they become extinct), to a potentially renewable one (it is possible to get more species than we currently have, although not necessarily every species that is extinct There is an interesting implication in how the risk profiles of conservation managers are likely to change with this reformulation. Similar to real options and adaptive management thinking, managers might be more willing to try high risk/high reward approaches to management when extinction is reversible if something does not go as planned (Chadès et al. 2015). This could be beneficial to conservation if it counteracts the tendency to constrain actions to those that are tried and true rather than trying untested initiatives that may provide better outcomes but are outside the conservative risk preference (Tulloch et al. 2015). Alternatively it would be detrimental to conservation if it led managers to rush into high risk activities without thinking about possible consequences, or if there was an unintended decrease in public support for conservation if people decided that extinction did not matter because extinction could always be reversed later (Norton 2010; Minteer 2014).

Figure captions:

Figure 1: Reversible link between states when de-extinction is possible. A) Currently, management enhances the ability of rare species to remain extant but they go extinct at some rate. Once extinct they remain extinct with probability = 1. However, B) de-extinction permits the transfer of some species from extinct to extant (or possibly even extant to extinct to extant), as a deliberate management action. This changes the problem formulation and the actions available.

Figure 2: Payoff matrix to demonstrate the importance of considering probability of successful de-extinction. Each cell in the matrix displays the probability of success given the action for species 1 in bold font and the action for species 2 in italic font. De-extinction action necessarily includes successful management for persistence while extant so the value is calculated as p(successful persistence with management while extant)*p(successful de-extinction). If the current budget is insufficient to exercise the option with the greatest benefit (manage spp. 1 and 2) the manager will choose the combination of actions that provides the next greatest cumulative benefit (Manage sp. 2, de-extinct sp. 1), with a simplifying assumption in this case that the benefit to cost ratio of all of the actions is the same.

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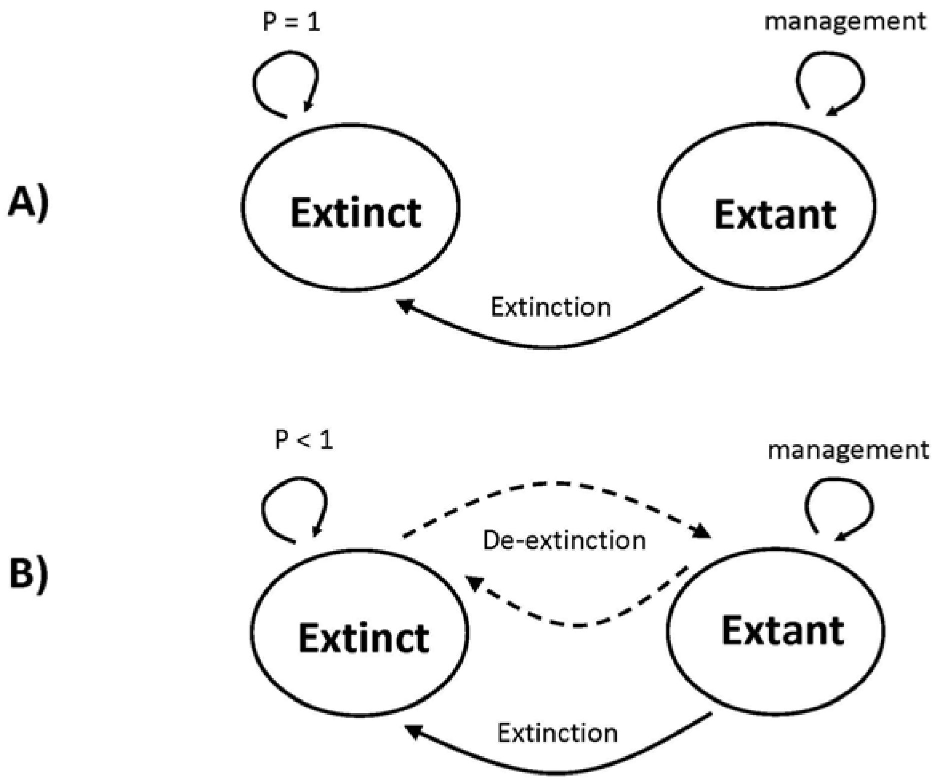

	Manage Spp. 2	*De-extinct Spp. 2*
Manage Spp. 1	**0.8** + *0.6* = 1.4	**0.8** + *0.01*0.6* = 0.81
De-extinct Spp. 1	**0.8*0.5** + *0.6* = 1	**0.8*0.5** + *0.01*0.6* = 0.41